Long baseline neutrino experiments

L. Chaussard

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6th International Workshop
Heavy Quarks and Leptons
Vietri, May 27 th - June 1st, 2002

Session 9 : ν oscillations

Long BaseLine ν experiments

(ν -wars , episode I to episode III)

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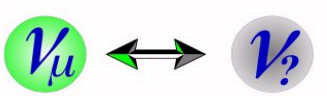
Prologue: Why do we need LBL ν experiments ?

- Two flavour oscillation: $P(\nu_\mu \rightarrow \nu_?) \sim \sin^2(2\theta) \sin^2(1.27\,\Delta m^2\,L/E)$

control ν flavour purity and fluxes
choose distance and energy

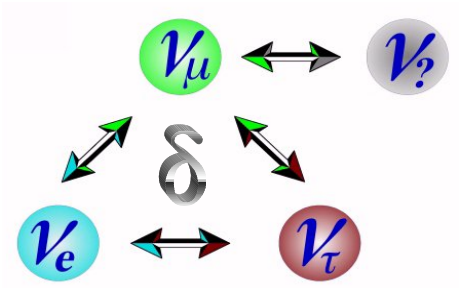


* $\sin^2(2\theta)_{min} \sim (L) / (M_{det.}^{1/2})$
* $\Delta m^2_{min} \sim 1 / (L^{1/2}\, M_{det.}^{1/4})$

→ vary L, large $M_{det.}$

(ref.: A. Ereditato, P.Migliozzi, La Rivista del Nuovo Cimento, vol.23 n.12 (2000) 1-136)

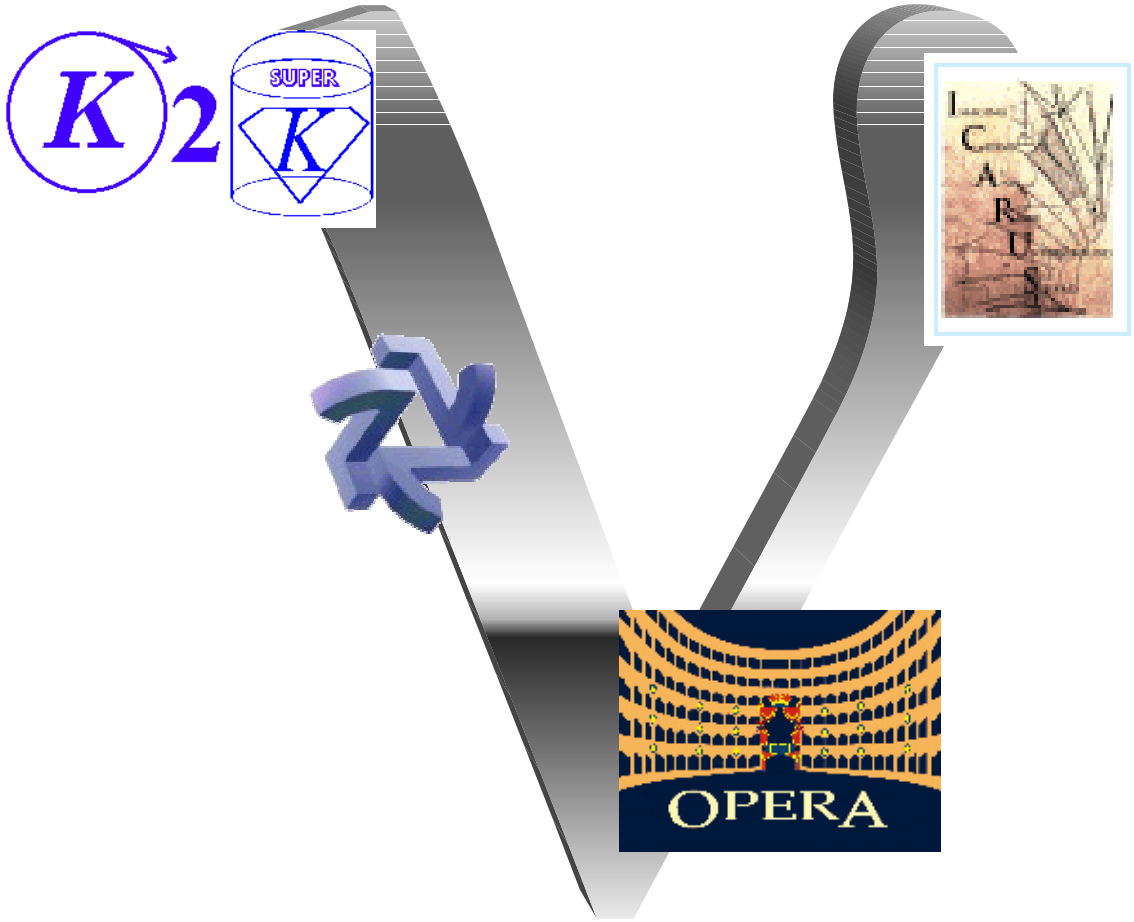
- Three flavour oscillation:



3 angles θ_{ij}
2 mass differences Δm^2_{ij}
1 ~~CP~~ phase δ

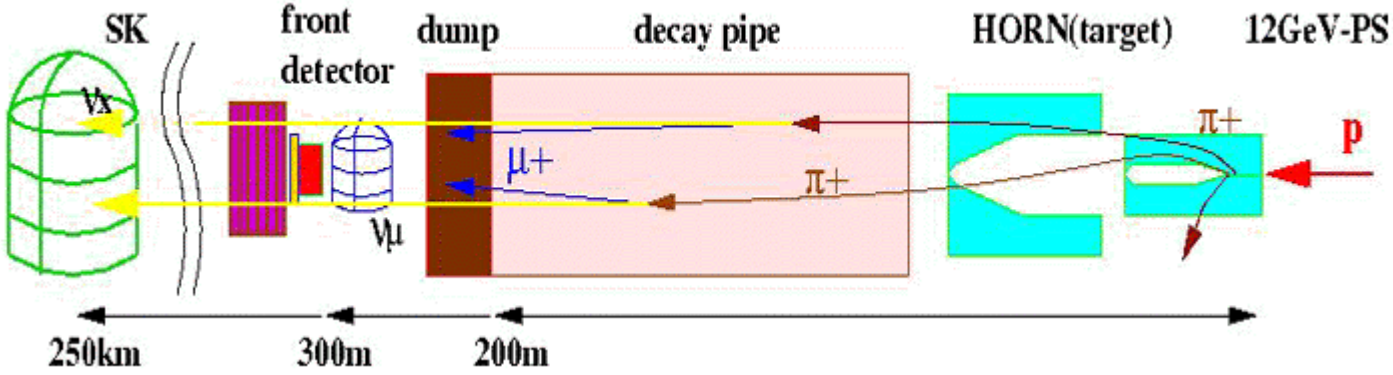
ν and $\overline{\nu}$

Episode I: "Standard" neutrino beam experiments



K2K: from KEK to SuperKamiokande

- "disappearance" experiment
- 12 GeV protons on Al target, 1.3 GeV ν_μ beam from π decay
- near detector @ 300 m: 1kT water Cerenkov
  + SciFi tracker + μ range detector
- far detector @ 250 km: 50 kT (22.5 kT fiducial vol.) water Cerenkov
- status: started March '99
  SK accident on 12th of November 2001

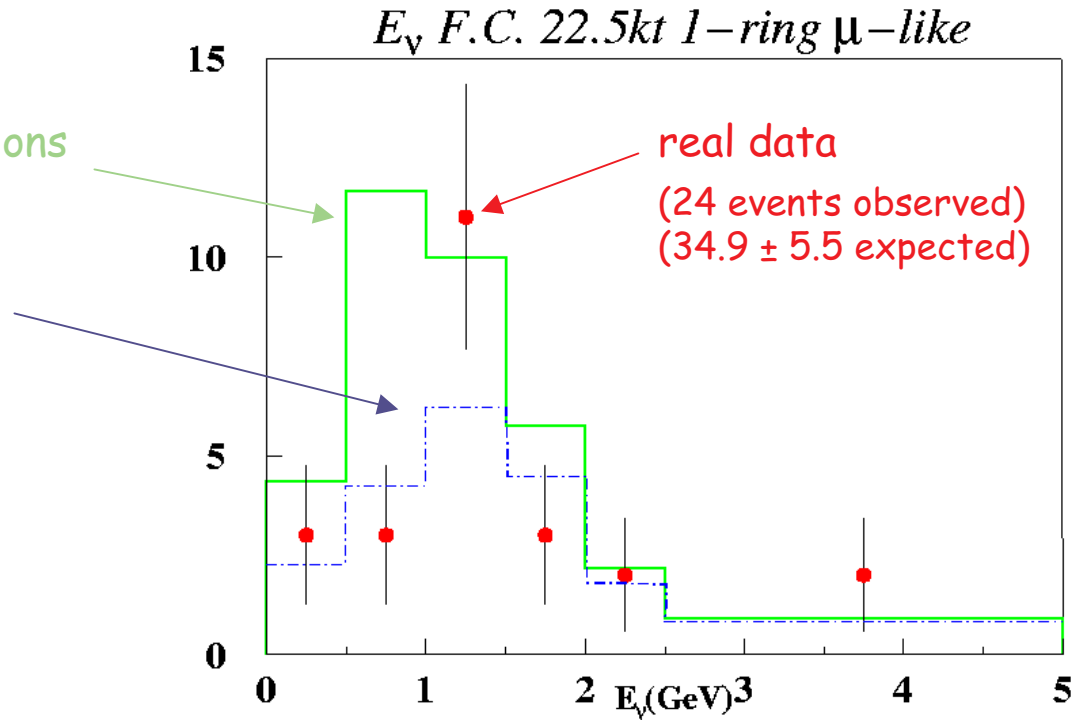


K2K: from KEK to SuperKamiokande

- hep-ex/0110034 v1 - 17 Oct.2001: using ~ 0.4 10^{20} p.o.t.

  44 fully contained events observed

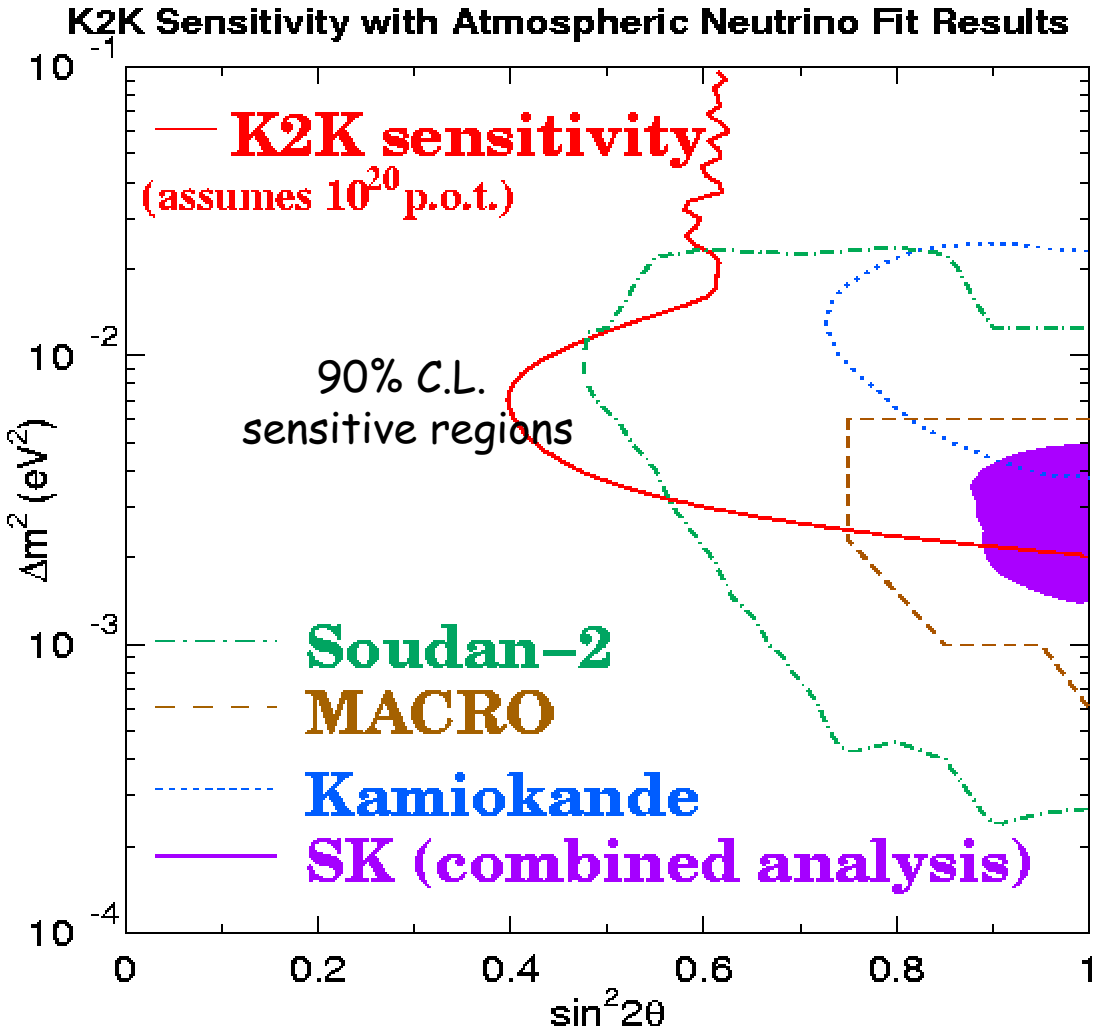
  $64^{+6.1}_{-6.6}$ expected without oscillation



- no oscillation hypothesis disfavored at ~ 2σ

K2K: from KEK to SuperKamiokande

- expectations for 10^{20} p.o.t. (3-4 years more data taking):



NUMI/MINOS: from Fermilab to Soudan

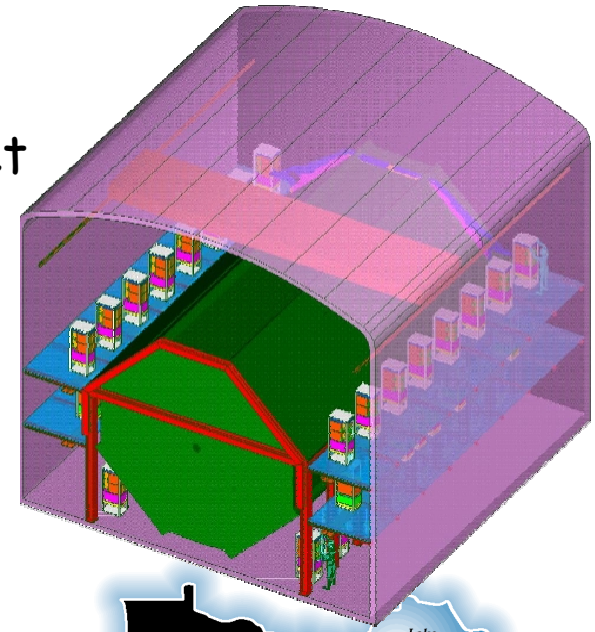
- "disappearance" experiment

- 120 GeV protons on graphite or Beryllium target
- 1 to 25 GeV ν_μ beam (3 configurations)

- near detector @ 290 m: 0.98 kT
- far detector@ 730 km: 5.4 kT

- far detector (extracted from S. Childress at NBI 2002) :

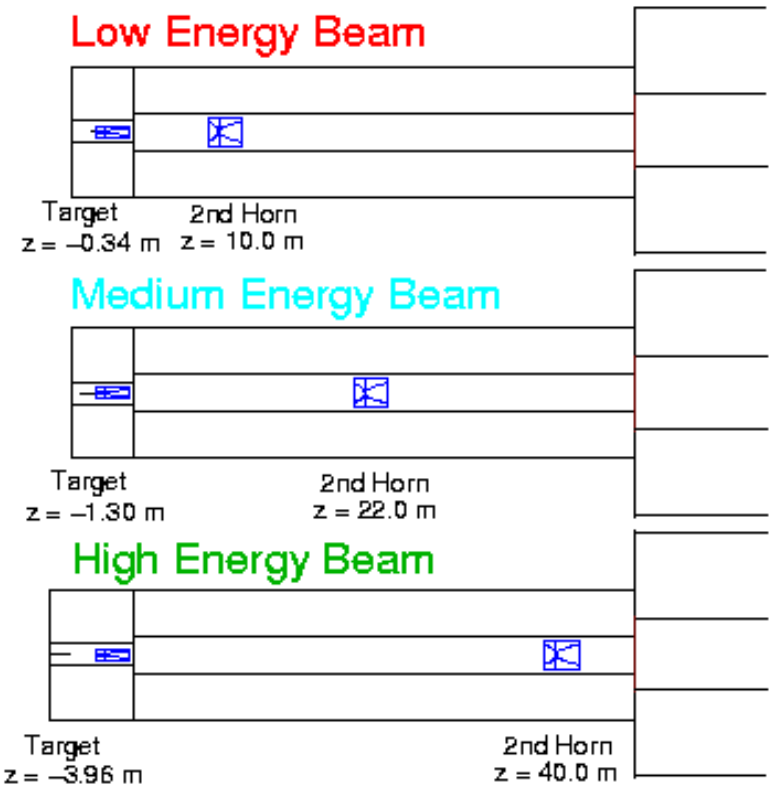
8m octogonal tracking calorimeter,
486 layers of 2.54 cm Fe, 2 sections, each 15 m long,
4.1 cm wide plastic scintillator strips, WLS fibers + P.M.,
25 800 m^2 active detector planes,
magnet coil $\langle B \rangle \approx 1.3T$

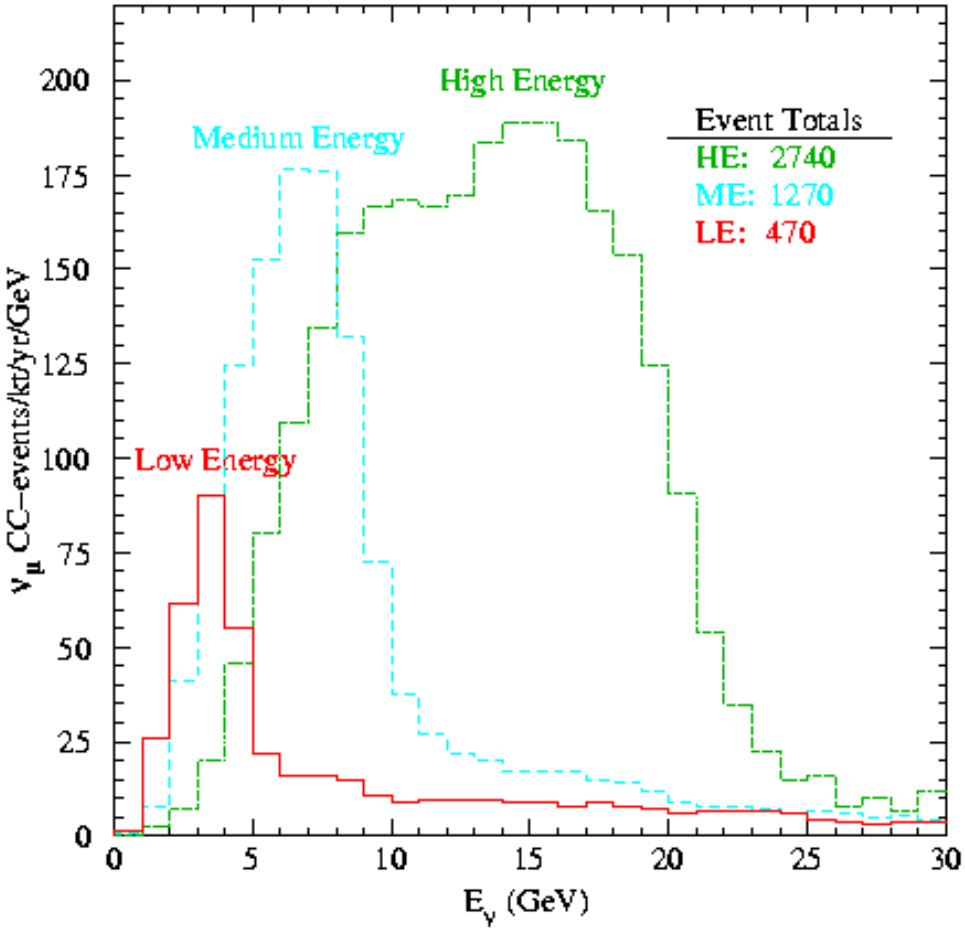


- status: far detector operational by late 2003
  near detector complete and tested late 2004
  beam commissioning ~ end 2004/ early 2005

NUMI/MINOS: from Fermilab to Soudan

- 3 energy configurations:

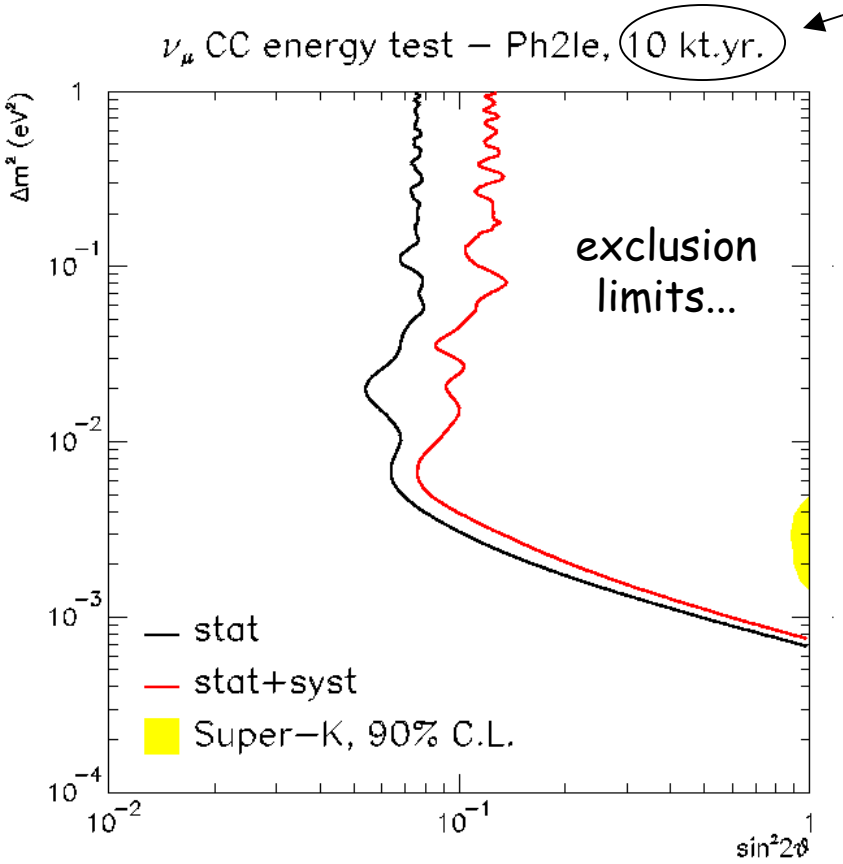


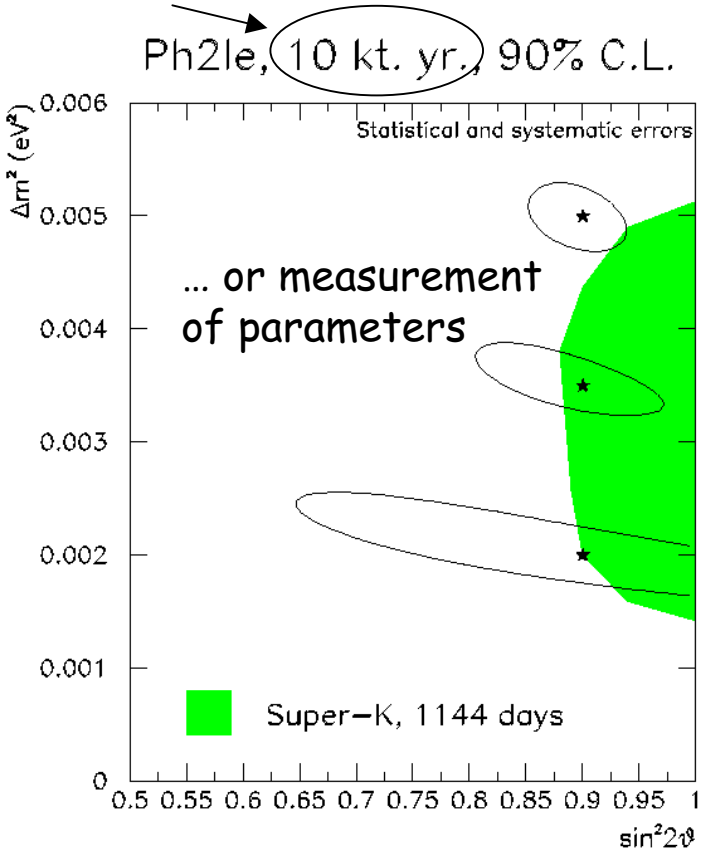


NUMI/MINOS: from Fermilab to Soudan

- many plots available from: http://www-numi.fnal.gov/blessed/index.html
- including stat. and syst. errors , for the 3 energy configurations
- for CC energy test, NC/CC ratio, $\nu_\mu \rightarrow \nu_e$, ν_s ...

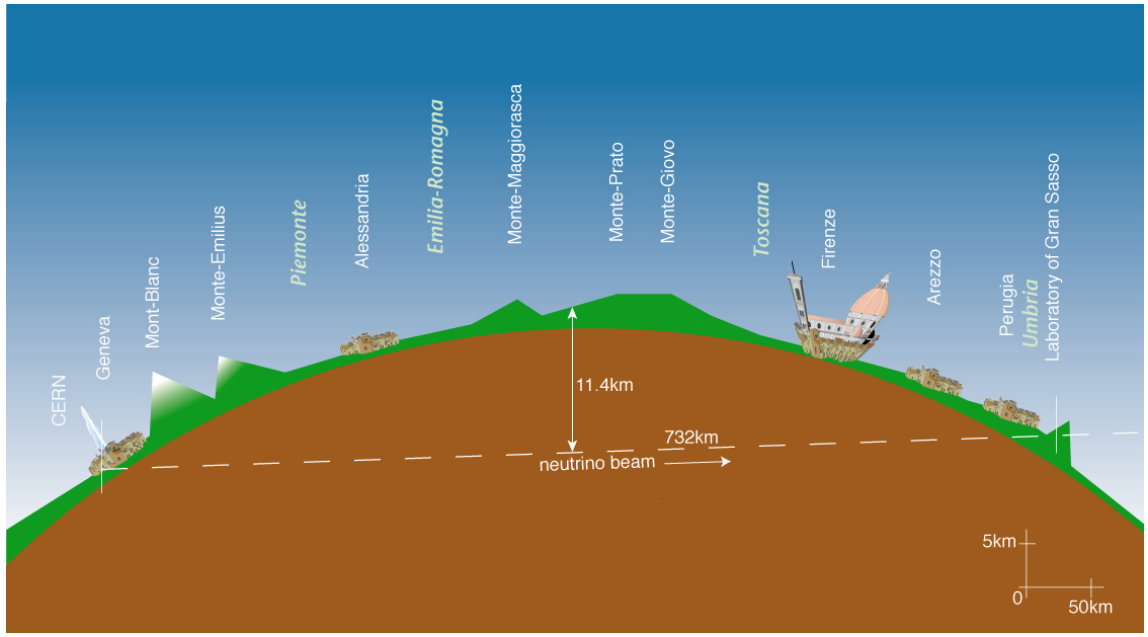
~ 2 years data taking

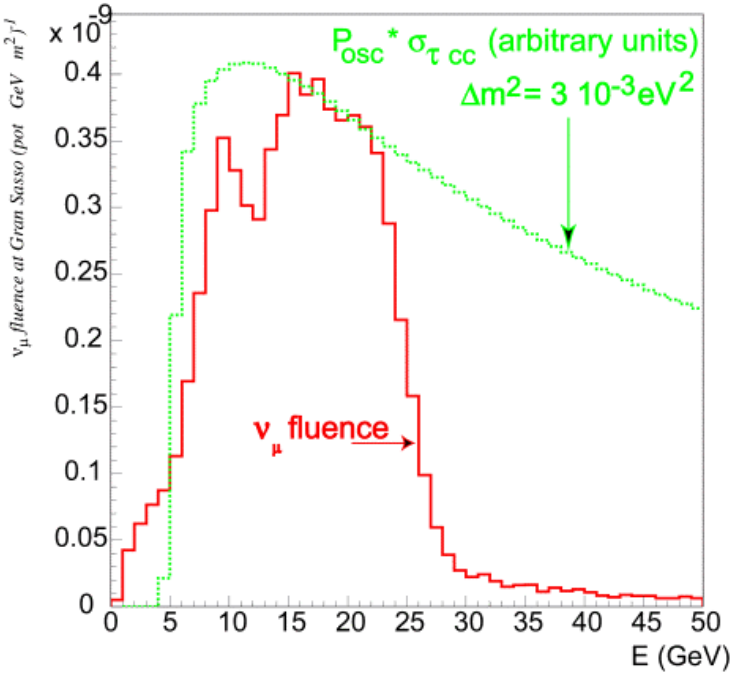




CNGS: from CERN to GranSasso

- 400 GeV protons on graphite target
- 15 GeV ν_μ beam

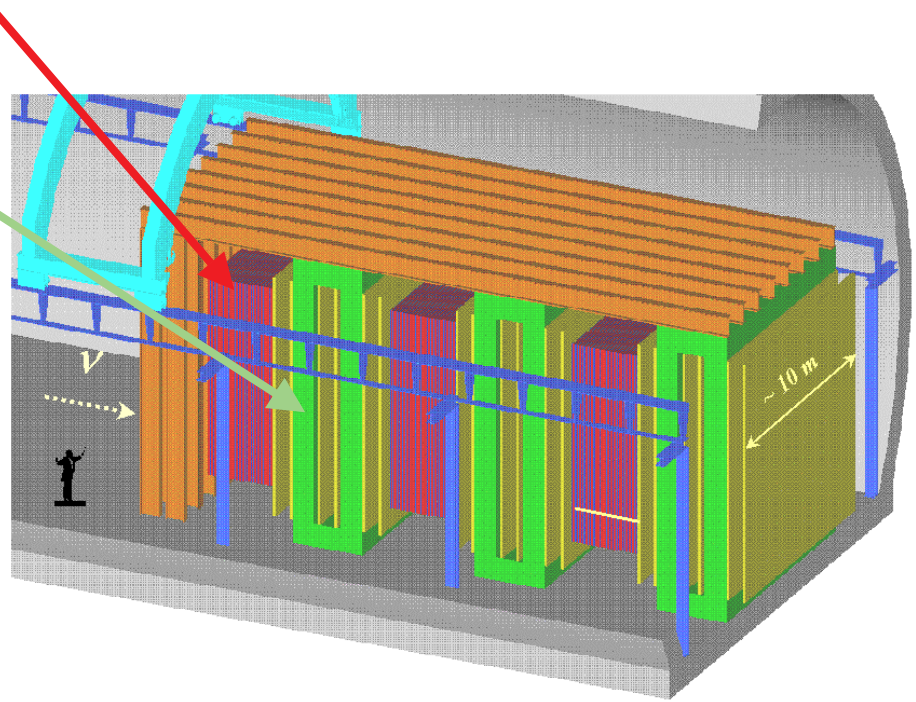




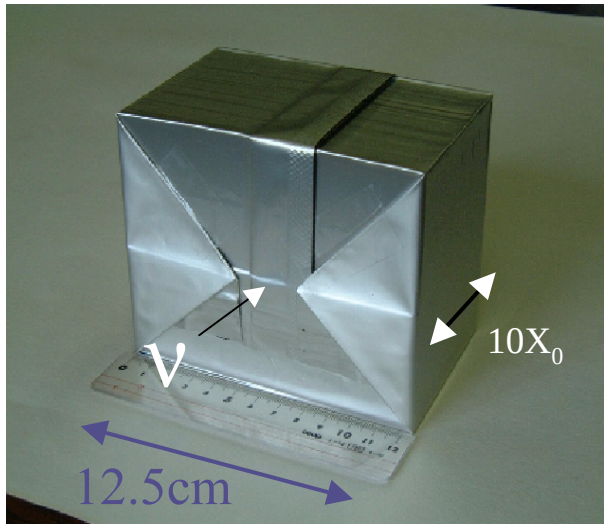
- status: K. Elsener @ NBI 2002: "CNGS is on schedule but..."
  first beam in Spring 2006 ... ?

CNGS1: the OPERA project

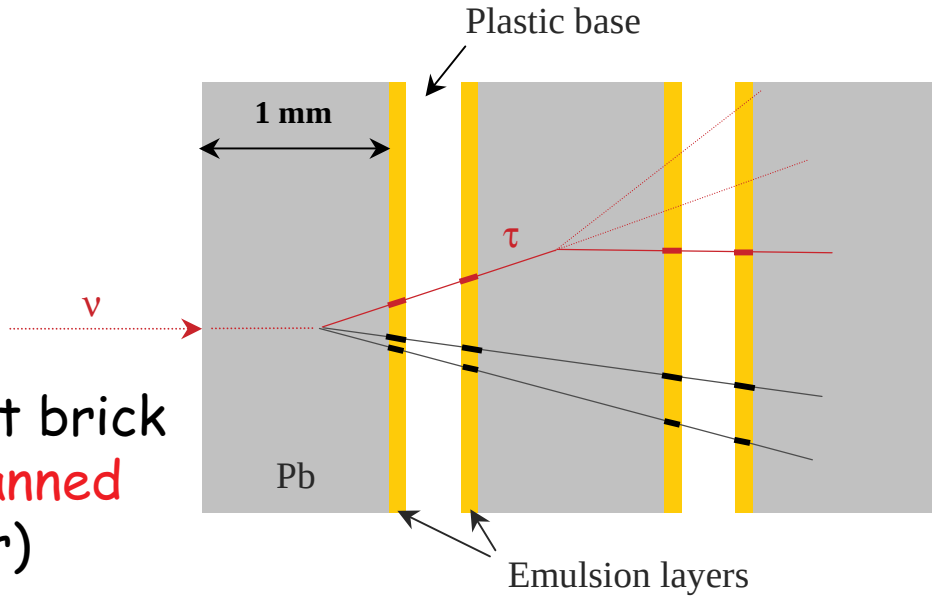
- "appearance" experiment
- far detector 1.8 kT @ 730 km
- target tracker: emulsions sheets + lead,
  plastic scintillators, WLS fibers + P.M.
- spectrometers: drift tubes
  + resistive plate
  chambers (RPC)
- status: approved by CERN and
  LNGS in February 2001,
  constr. starts end 2002,
  scheduled for 2006



CNGS1: the OPERA project



- Components:
  - 2 supermodules
  - 31 walls / supermodule
  - 52 x 64 bricks /wall
  - 56 emulsion films / brick



- Principle of the detection:

  scintillators allow to find the hit brick (~ 30 bricks / day), which is scanned by microscopes (~ 20 cm² / hour) to find the "kink" of the tau

CNGS1: the OPERA project

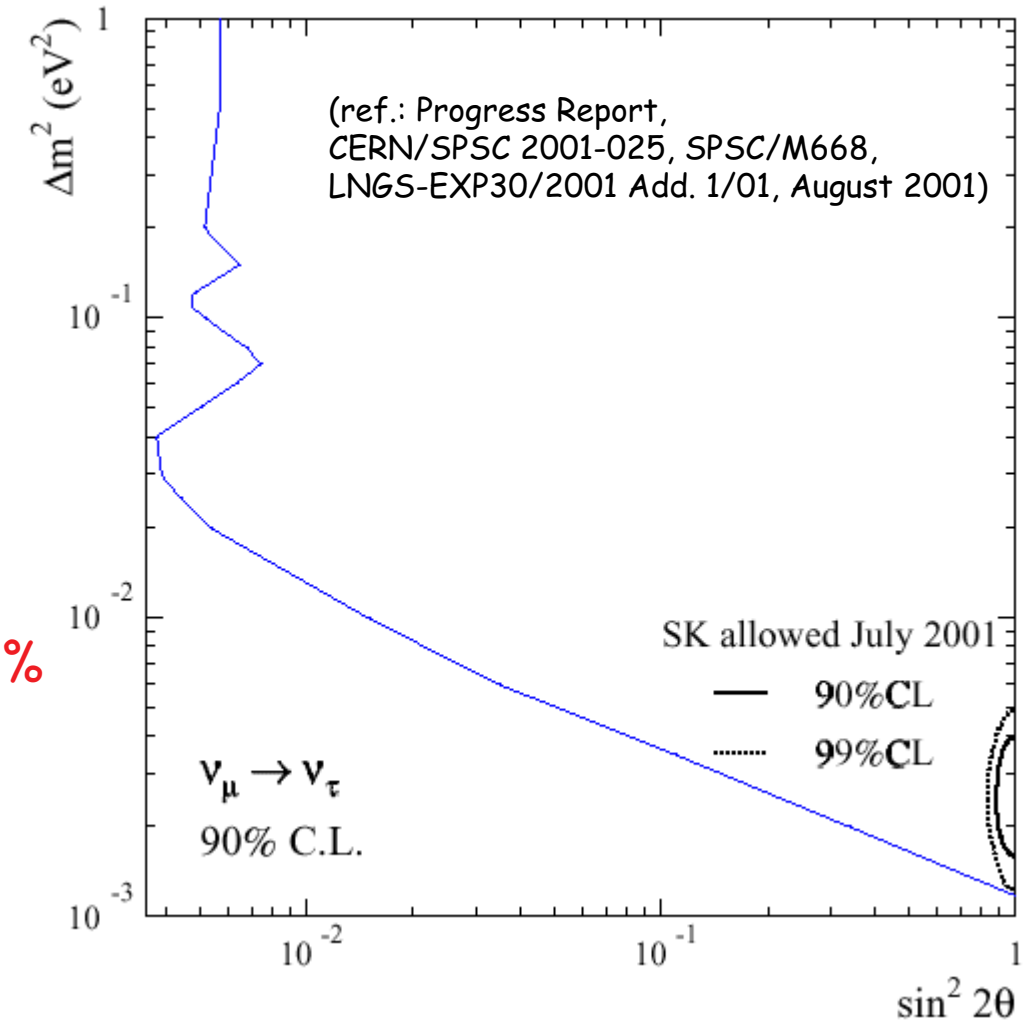
- expected number N of tau events: (5 years run with 1.8 kT average target mass)

$\Delta m^2 = 1.3\ 10^{-3}\ eV^2$: N = 4
$2.5\ 10^{-3}\ eV^2$: N = 10
$4.0\ 10^{-3}\ eV^2$: N = 26

- background: ~ 0.65 event
- proba. of 3σ significance for $\Delta m^2 = 2.5\ 10^{-3}\ eV^2$: ~ 99%
- room for improvement (efficiencies, beam x1.5 (?))

(ref.: Plan for the construction of the OPERA detector, May 2002)

- sensitivity (exclusion limits)



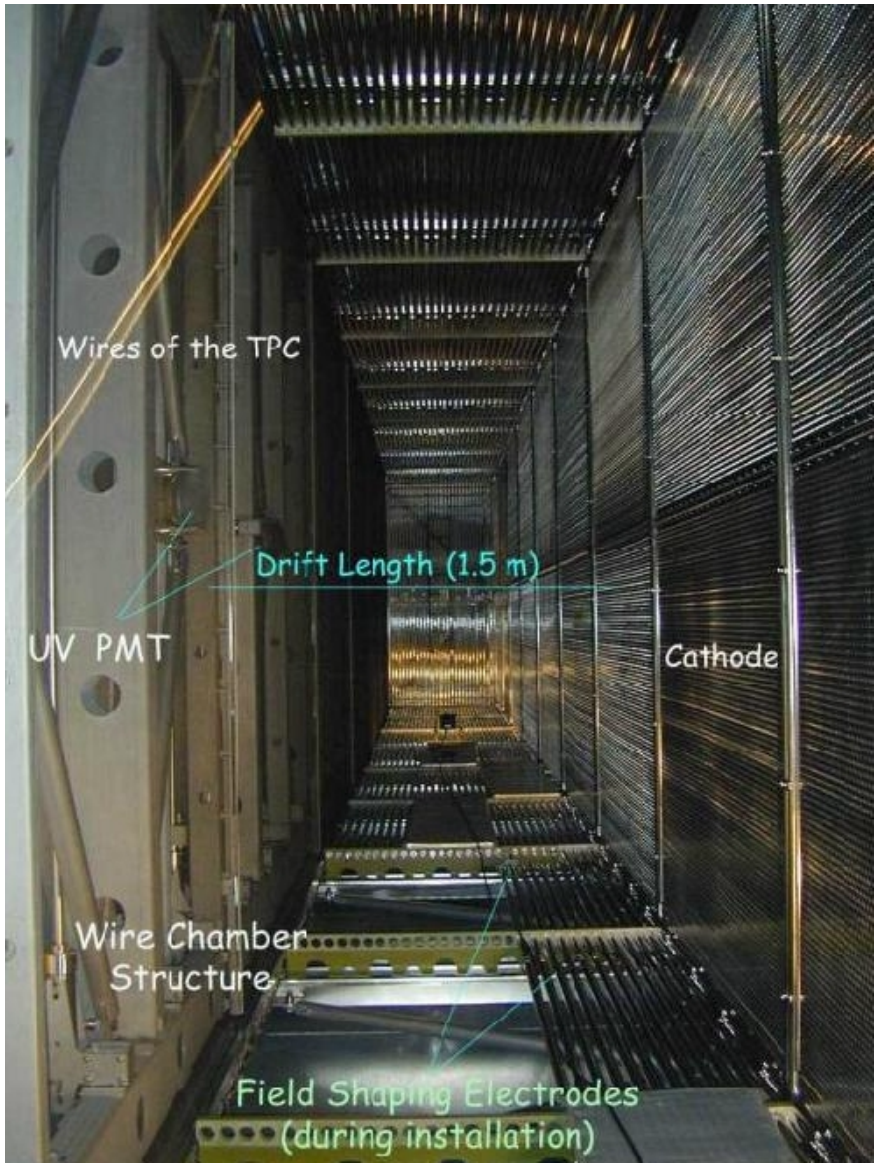
CNGS/ICARUS:

- Liquid Argon TPC, 300 T modules
- 3D reconstruction of tracks
- status: almost approved...

  T600 half-module mounted in Pavia March 2000 - March 2001

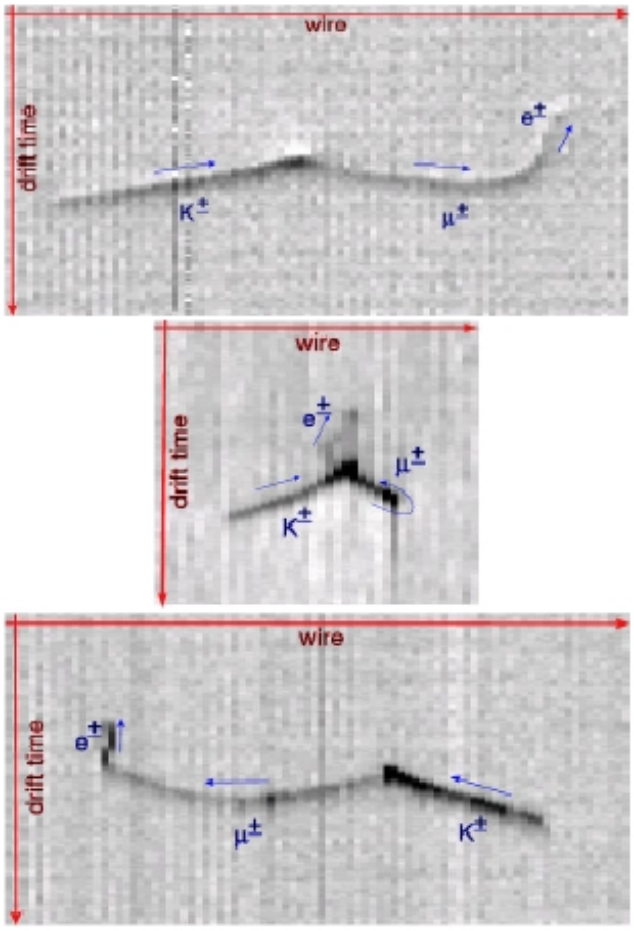
  full test run April-August 2001

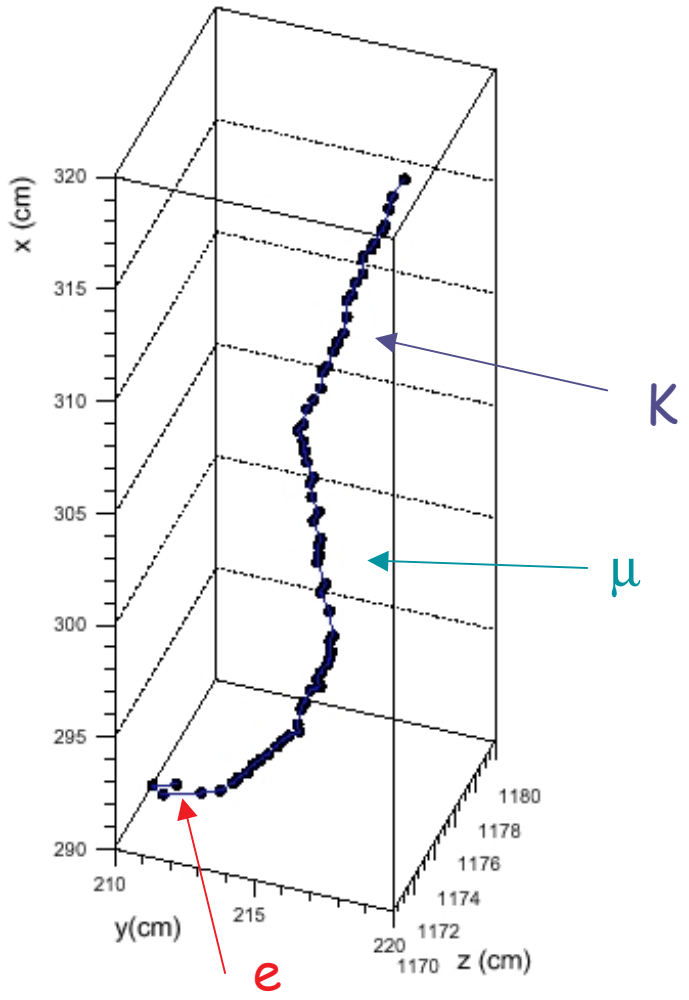
  installation and cosmic run at LNGS early 2003



CNGS/ICARUS:

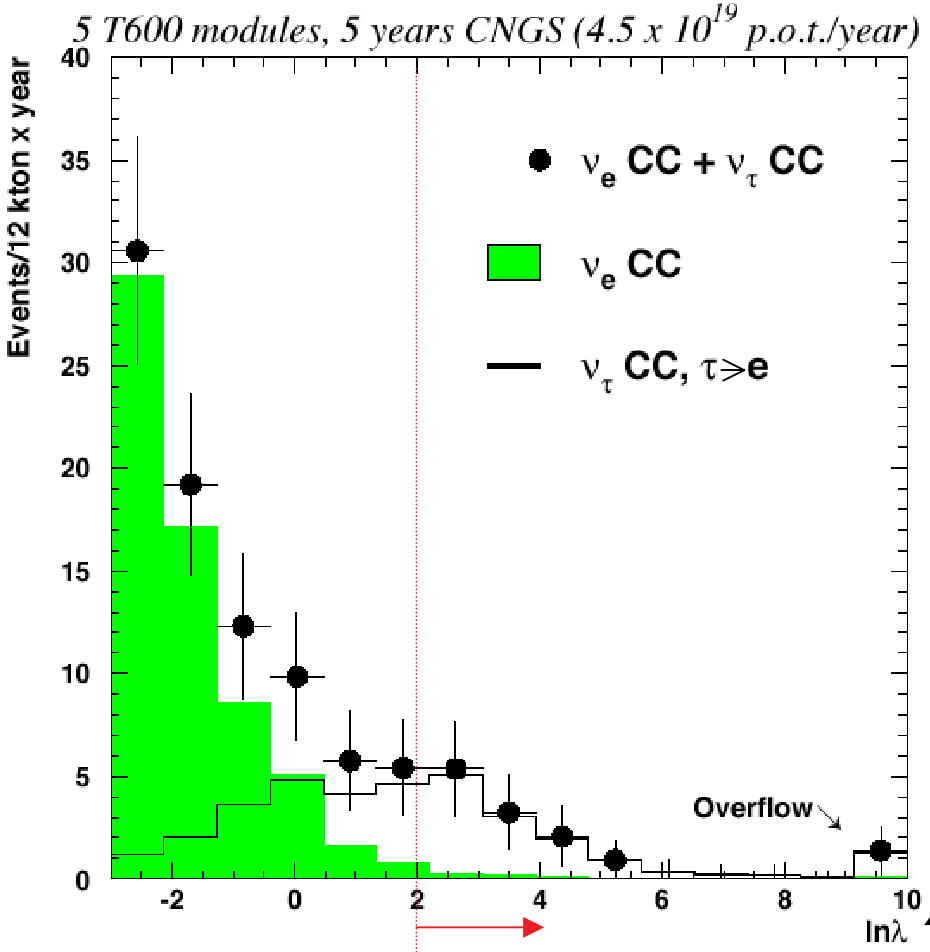
- real K → μ → e from the test run
  (ref. J.Rico, hep-ex/0205028 13 May 2002, Moriond Proc.)

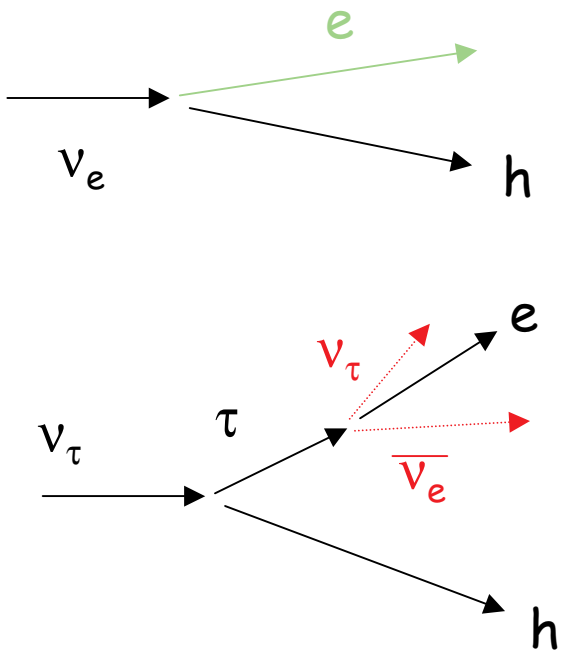




CNGS/ICARUS:

- $\nu_\mu \rightarrow \nu_\tau$ "appearance": example of the electron channel





"event shape" likelihood based on visible energy, missing P_t, $P_t(e)$, $P_t(h)$

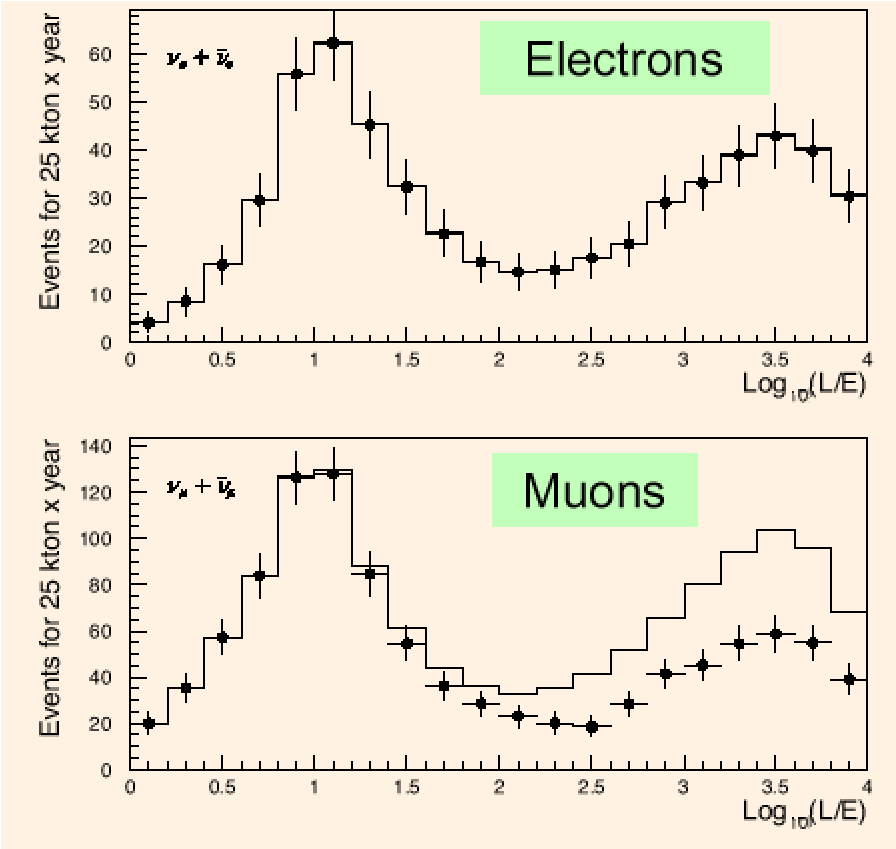
Cut at 2: 13 ν_τ CC, 0.7 ν_e CC

(ref. LNGS-EXP 13/89 add.2/01, November 2001)

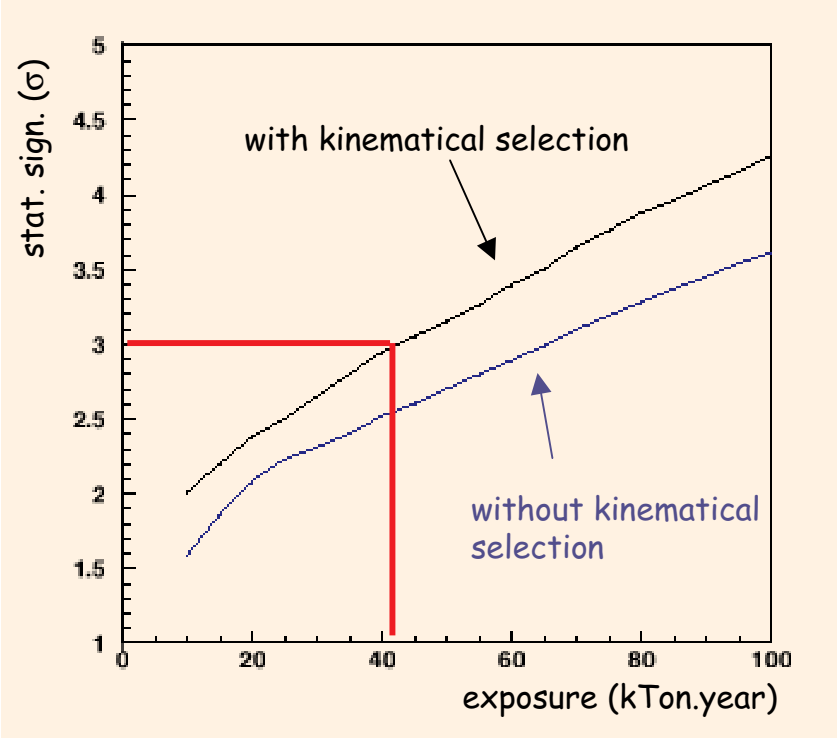
CNGS/ICARUS:

- **sensitivities** (ref. talk from A.Rubbia, NNN02, January 2002)

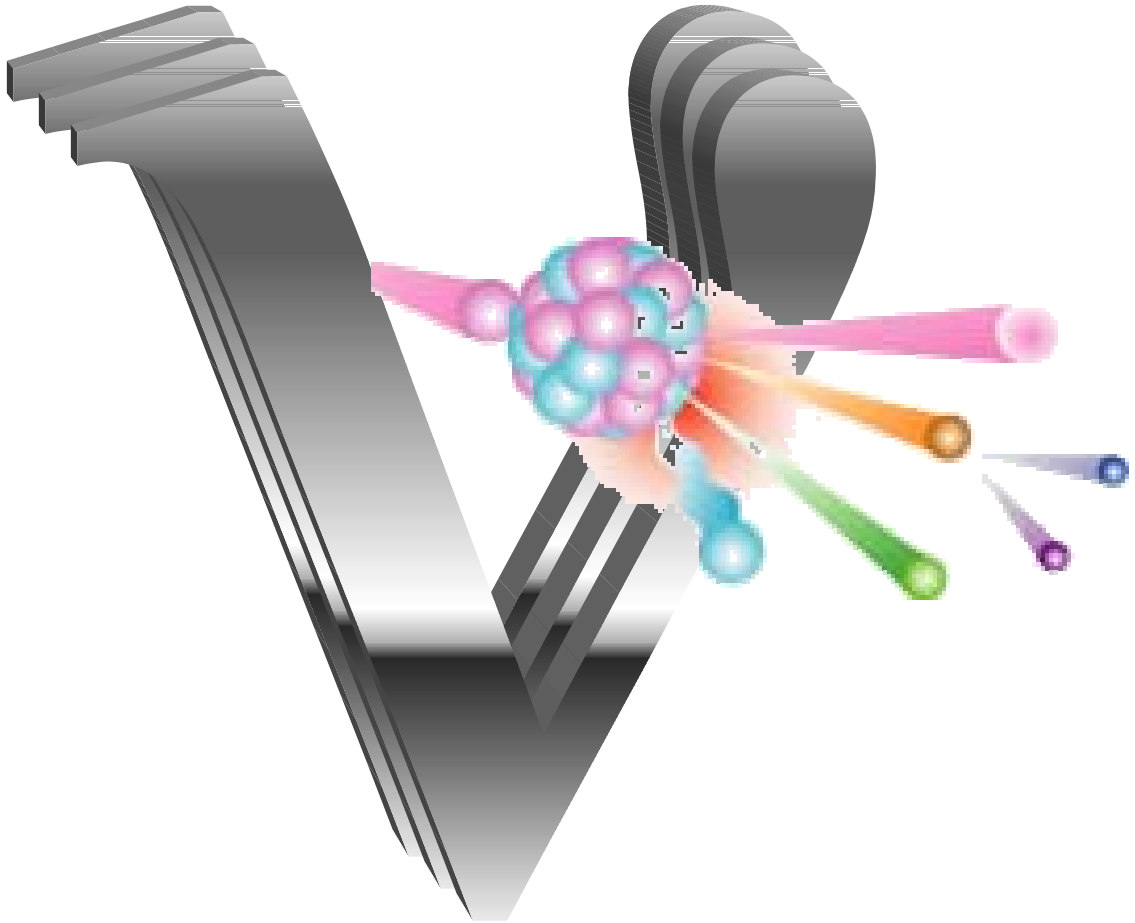
ν_μ disappearance
by CC energy test
(Δ (L / E) ~ 30%)



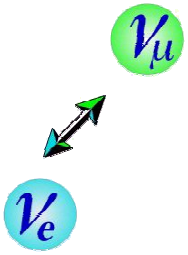
tau "appearance"
by missing P_t studies
3 σ effect: 40 kT.year ??



Episode II: "SuperBeams"



SuperBeams:



- physics: essentially $\nu_\mu \rightarrow \nu_e$
  push $\theta_{"CHOOZ"}$ limit

- technology:

  * increase proton beam intensity for a high luminosity ν beam
  * off-axis detectors to work at low energy (~GeV)
    and to reduce ν_e contamination

- possibilities:

  * Japan: JHF-I (0.75 MW) / JHF-II (4 MW)

  * U.S.A.: new 1 MW proton driver for the Fermilab Booster
    or x4 intensity of Fermilab Main Injector
    or Brookhaven AGS to Homestake or New Mexico

  * Europe: 4 MW proton linac at CERN ?

JHF: from Tokai to SuperKamioKande

- JAERI: 50 GeV PS delivers 3.3 10^{14} p / 3.3s (0.75MW)
  to be upgraded to 4MW
- Kamiokande: SuperK (22.5 kT) to be upgraded to HyperK (1000 kT)
- narrow band ν_μ beam ~1 GeV
- status : first phase approved
  starts 2007
- goals: measure...
  ..."everything" ?

(ref.: hep-ex/0106019, 5 June 2001)

JHF: from Tokai to SuperKamioKande

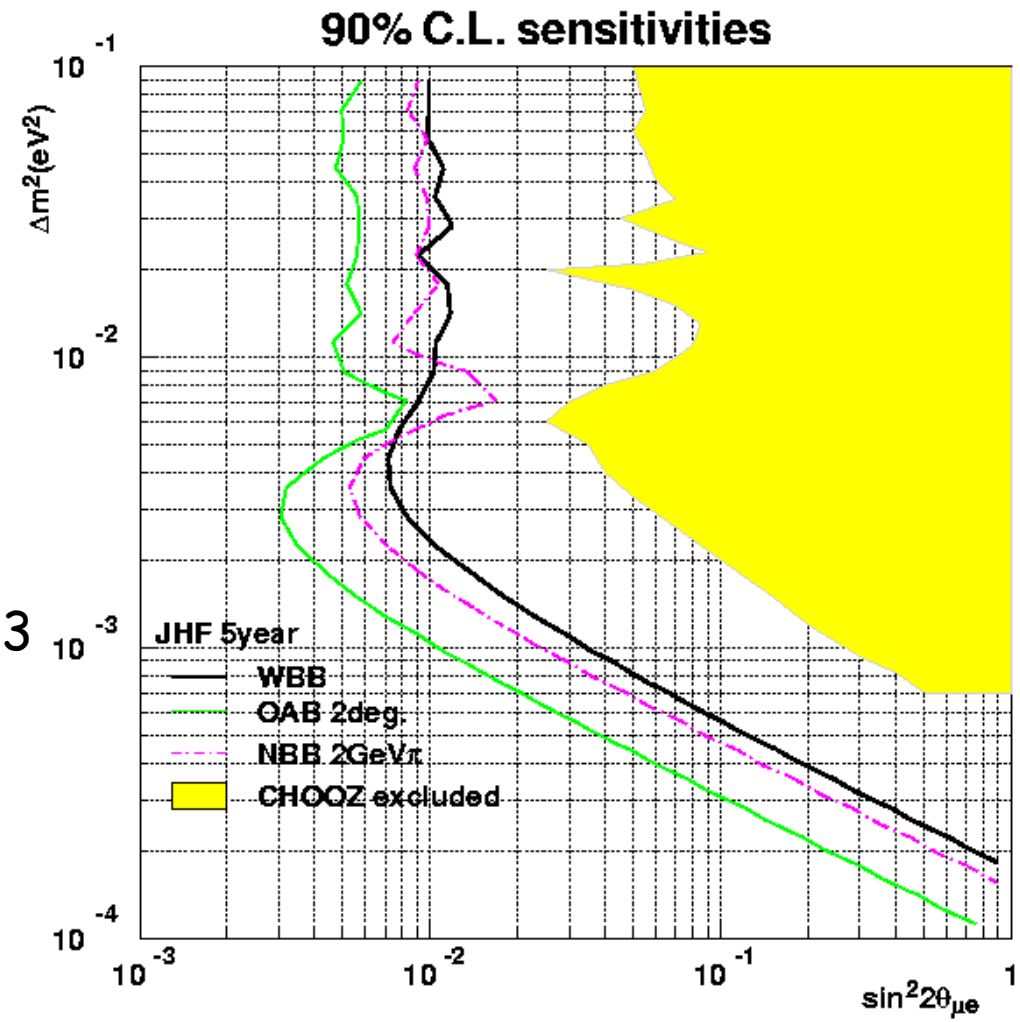
- ν_μ disappearance:
  gain an order of magnitude

  $\delta(\Delta m^2_{23}) \sim 10^{-4}\ eV^2$
  $\delta(\sin^2(2\theta_{23})) \sim 0.01$

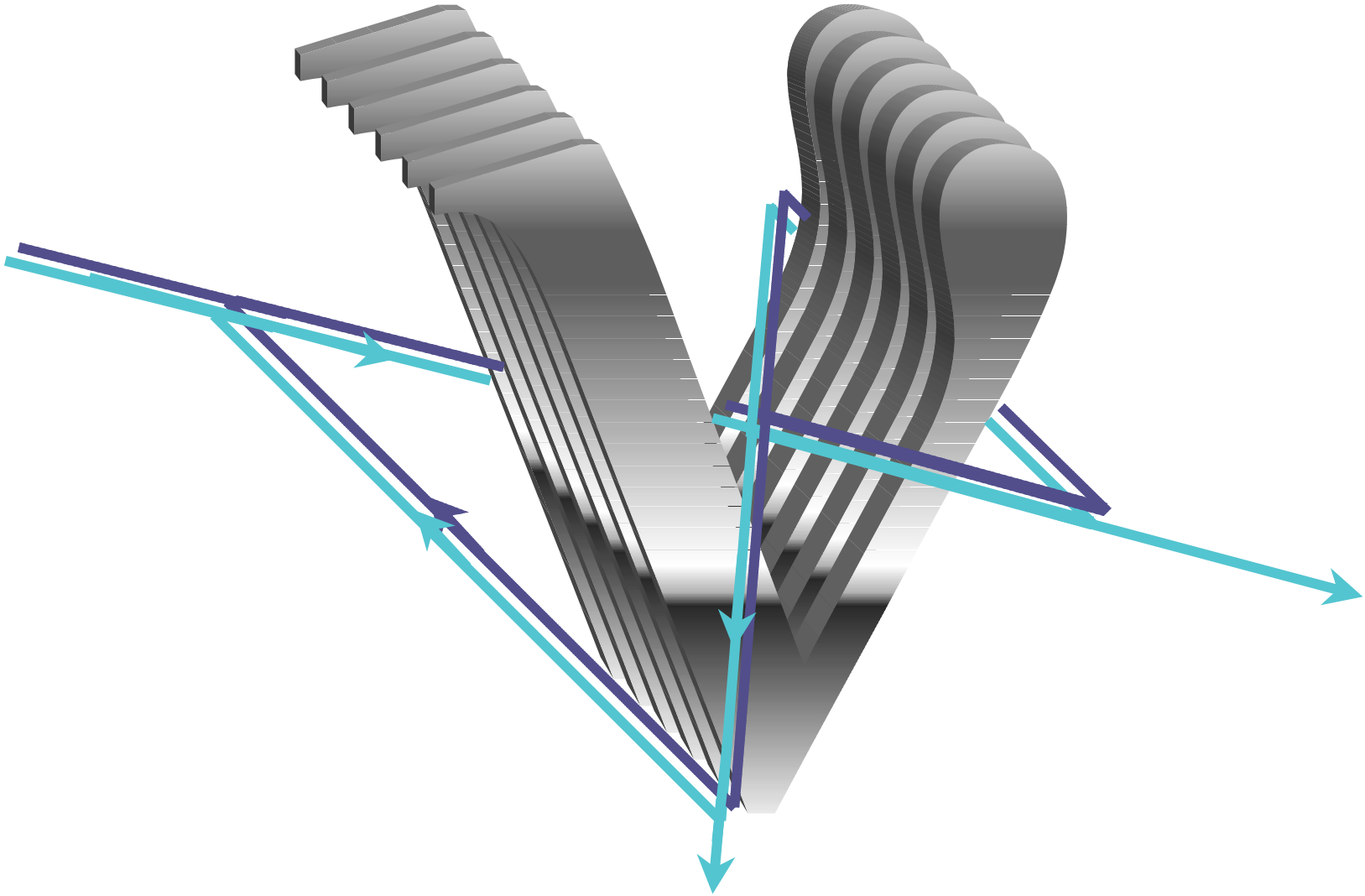
- $\nu_\mu \rightarrow \nu_e$: gain a factor 20

  $\sin^2(2\theta_{\mu e}) \sim 0.5\sin^2(2\theta_{13}) > 0.003$

- ~~CP~~ phase δ down to ~20°
  in the case of LMA solution

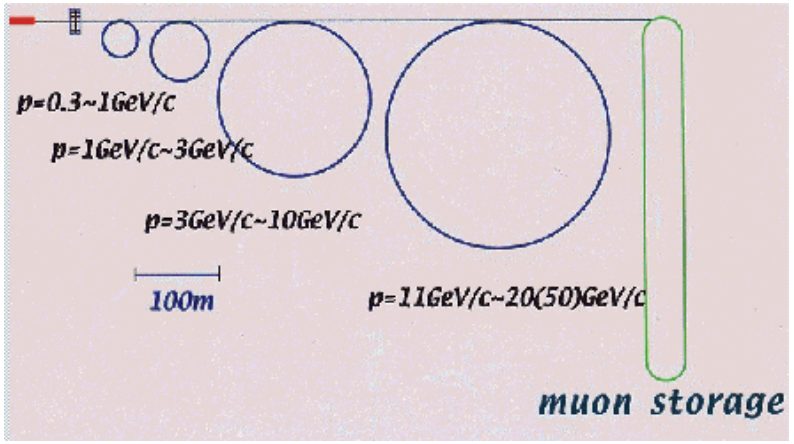


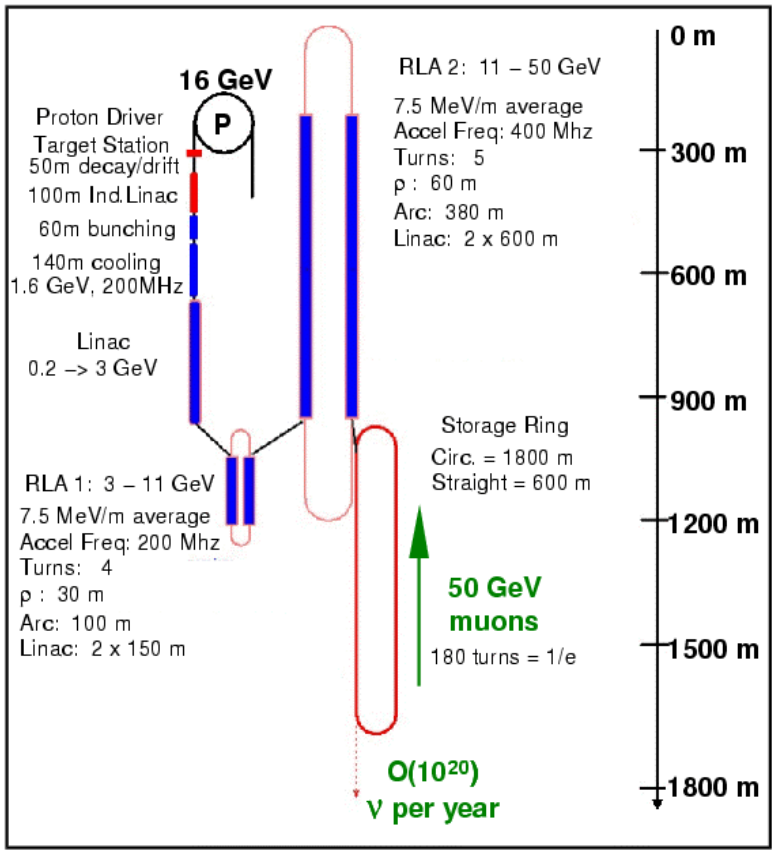
Episode III: "Neutrino Factories"

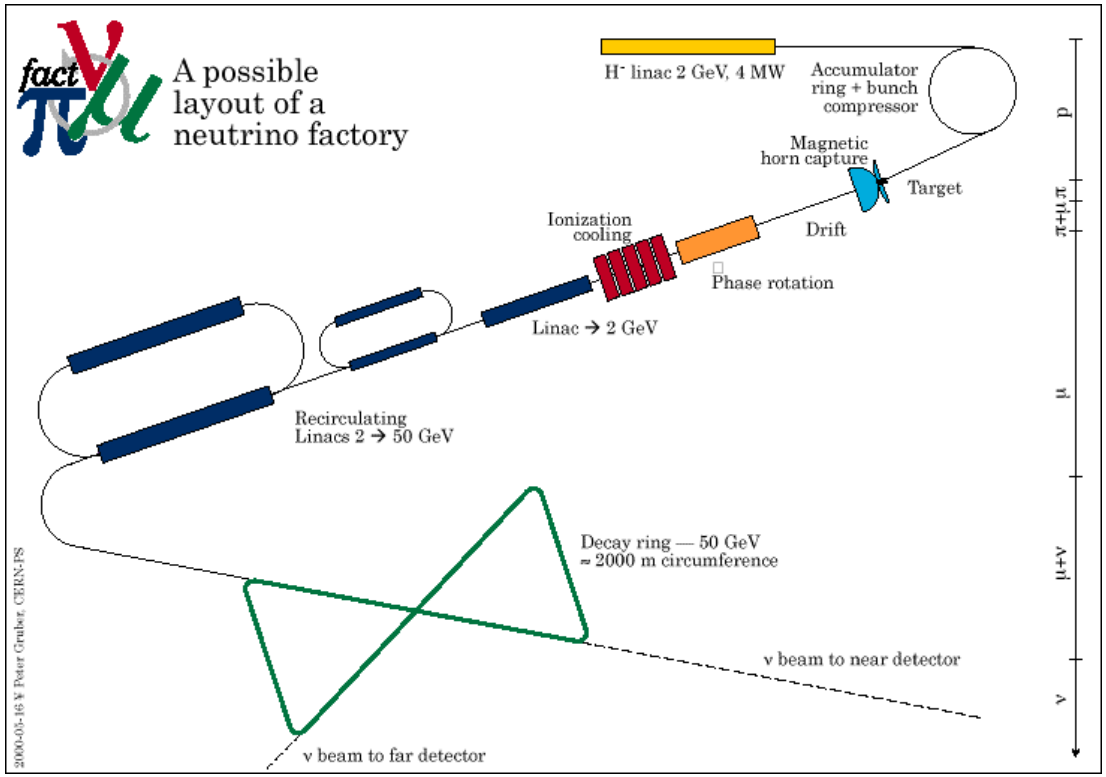


NuFact's:

- studies in US, Europe, Japan

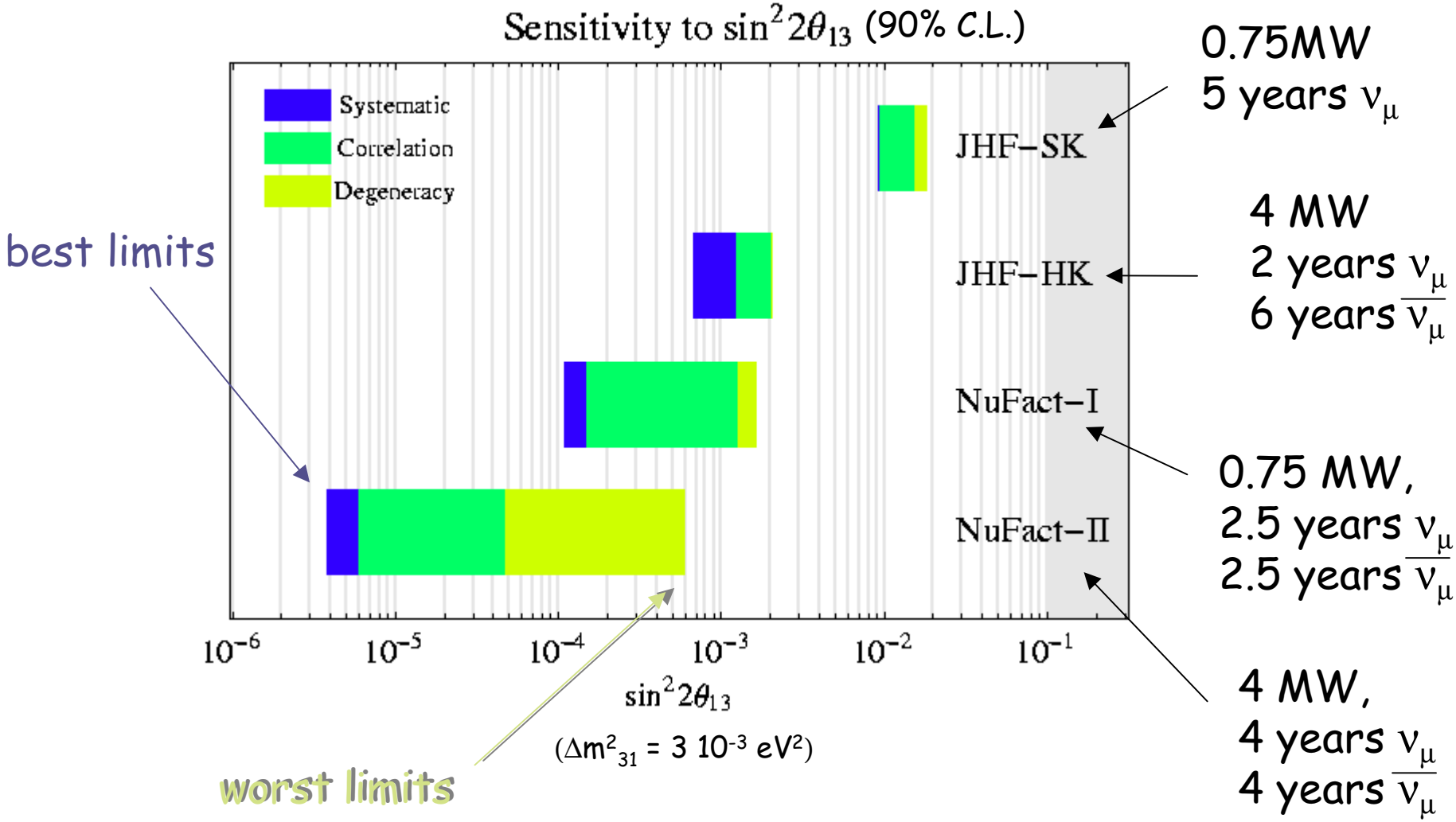






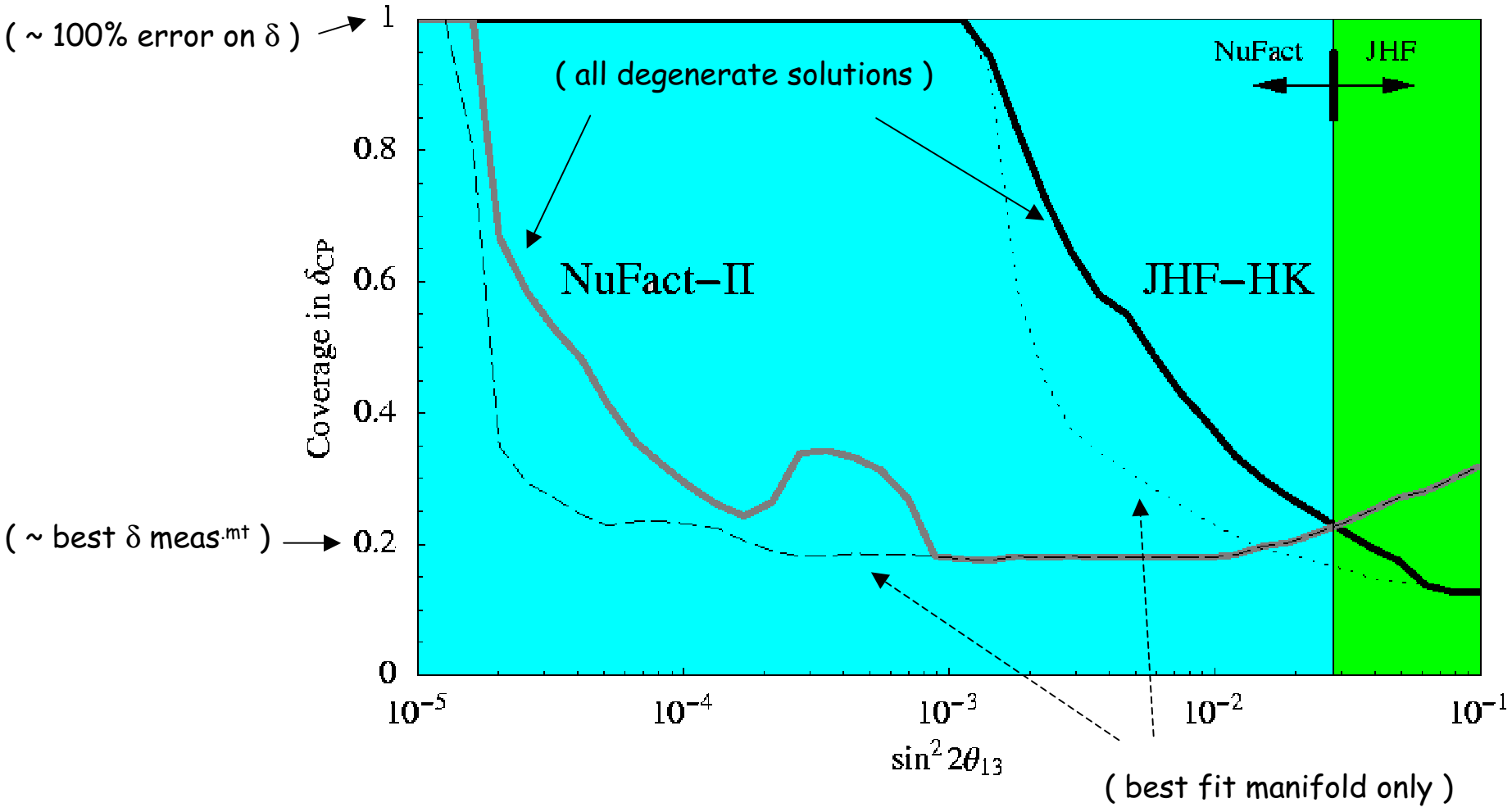
NuFact's or SuperBeams ?

- see for example hep-ph/0204352, 30 April 2002, P.Huber et al.



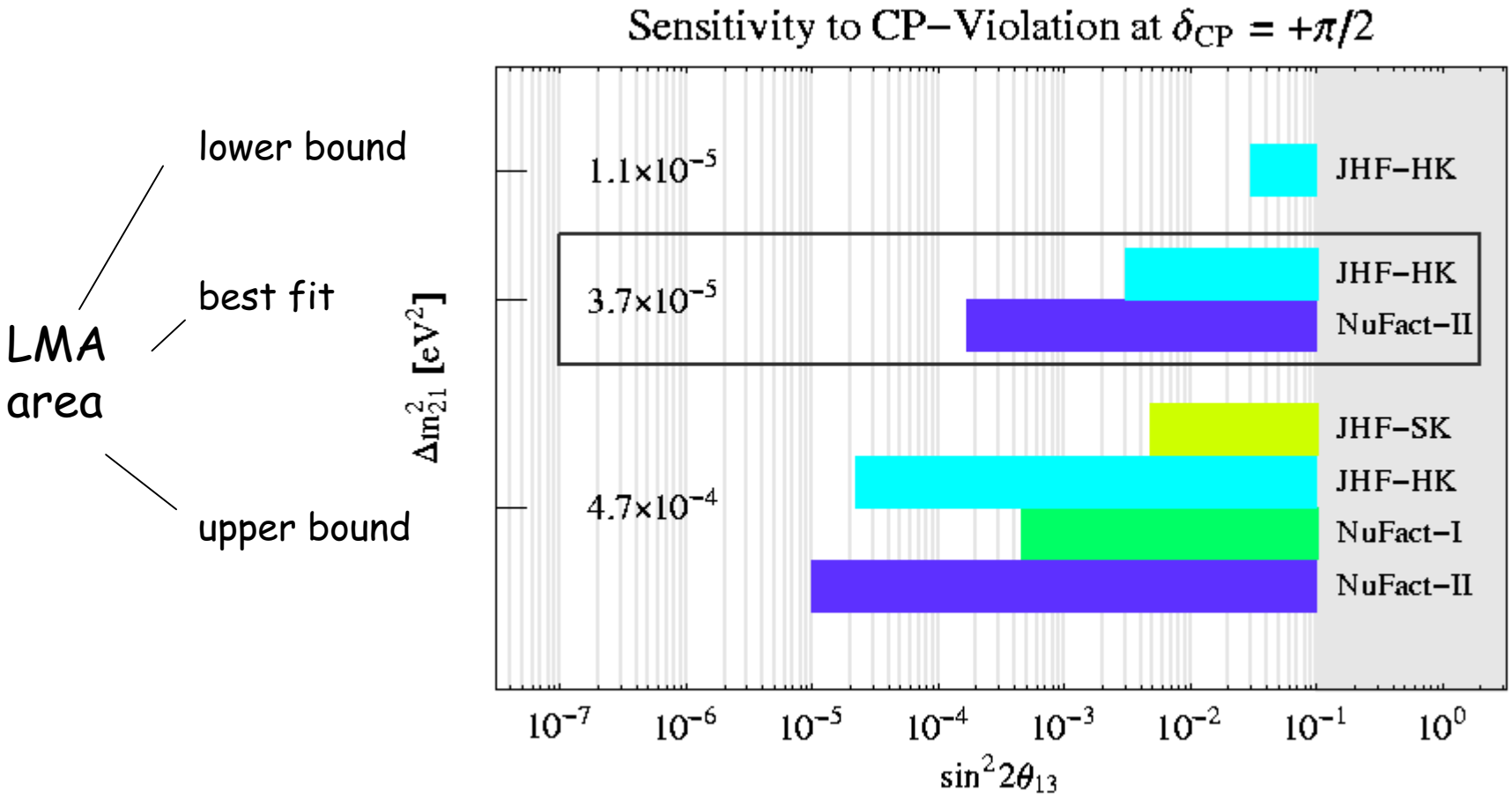
NuFact's or SuperBeams ?

- in the same ref., discussion of CP violation measurements
  (assuming LMA)

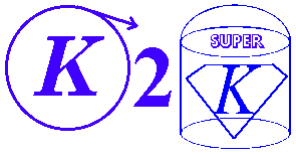


NuFact's or SuperBeams ?

- CP violation measurements

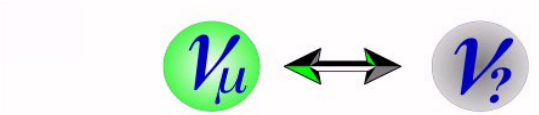


Epilogue (?):



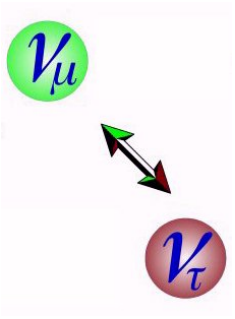
2001 ...

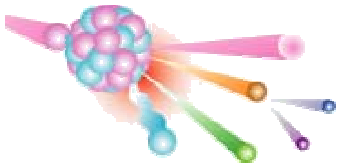
2005 ?



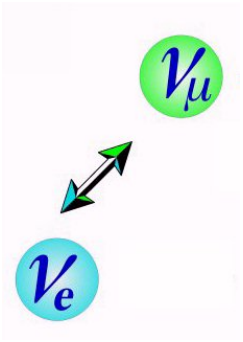
2006 ?

2006 ?





2007 ?



2015 ?